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(54) Variable bandwidth variable center-frequency multibeam satellite-switched router

(57) A reconfigurable switching router (10) connects to an existing constant band-width connectivity network (12) on board a multibeam communications satellite for increasing the flexibility thereof by providing variable band-width capability so that the satellite handles a multitude of individual users having different requirements of bandwidth and transmission rates. The bandwidth of at least one of a number of transponder channels (5 to 8) is split into two portions. A first portion is for single carrier traffic, while a second portion for multi-carrier traffic is further channelized in a reconfigurable fashion to achieve VBVCF subchannelization. The reconfigurable switching router utilizes a class of multi-level channelization formats implemented by a plurality of filter banks connected in parallel. A switching network performs VBVCF subchannel selection and routing via time and/or frequency multiplexing thereby to accommodate both VBVCF SSTDMA (satellite switched time division multiple access) and SSFDMA (satellite switched frequency division multiple access) traffic.
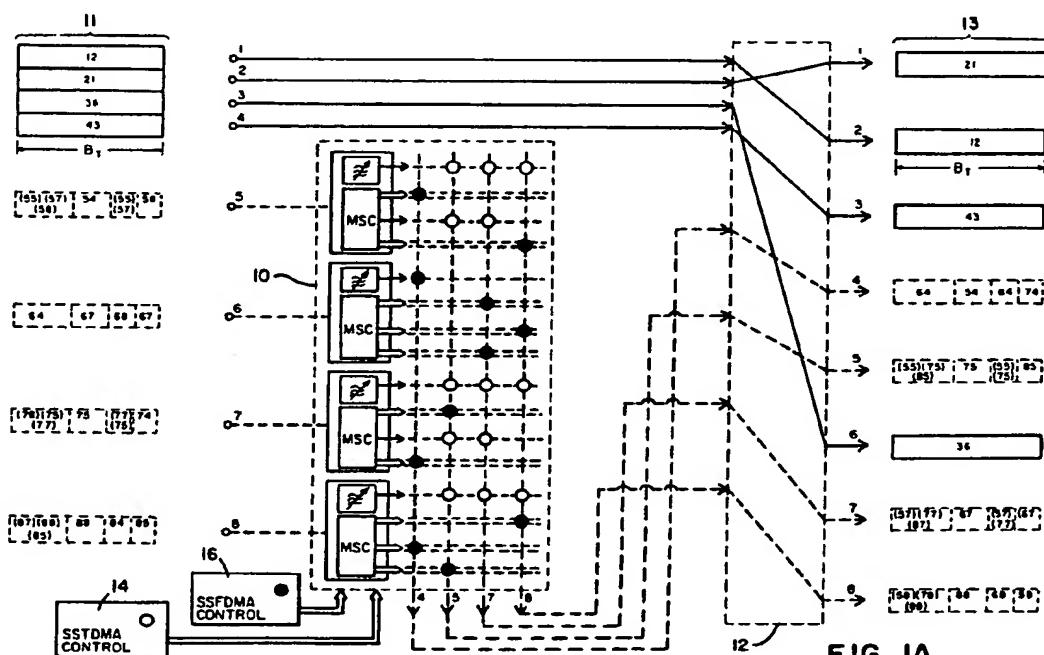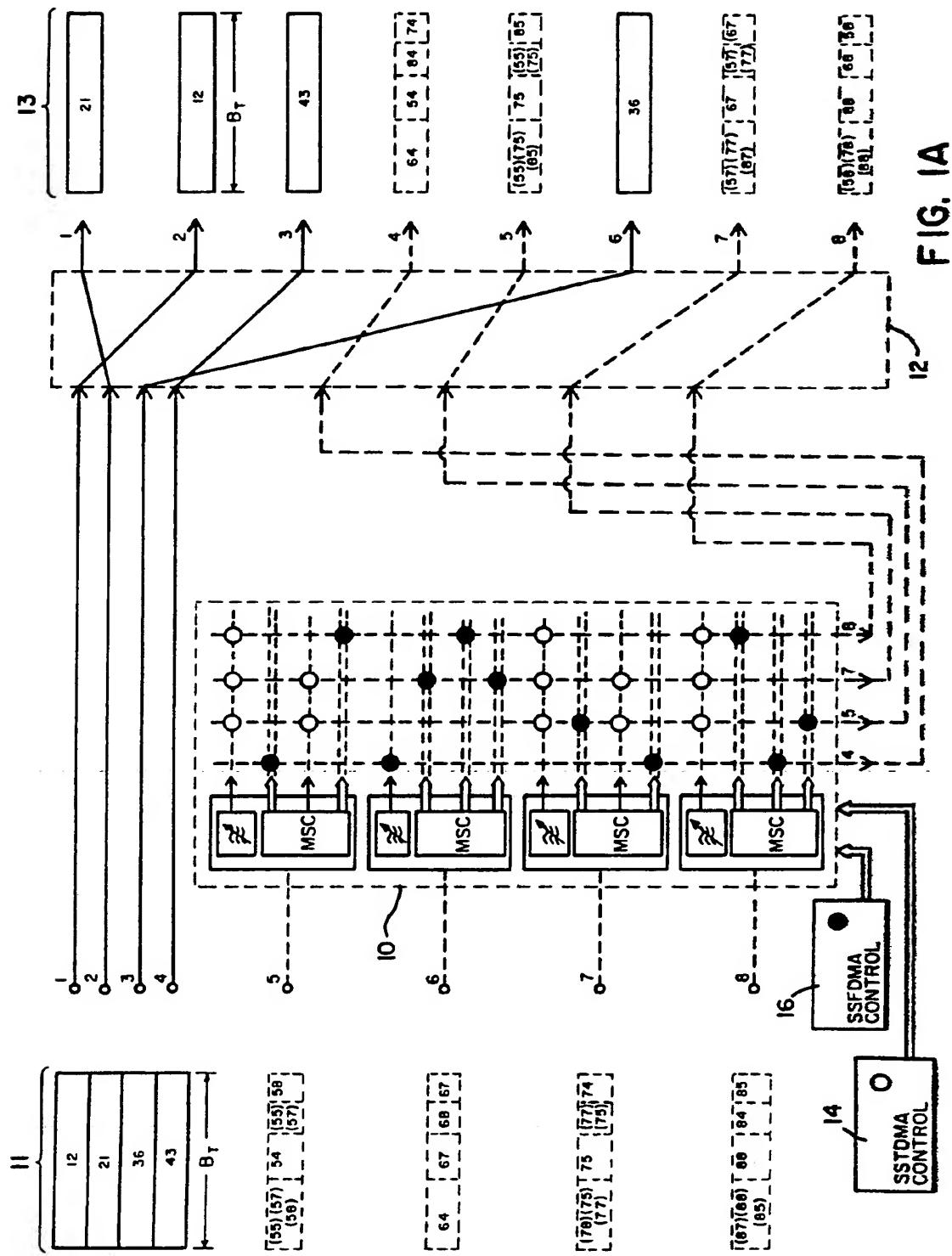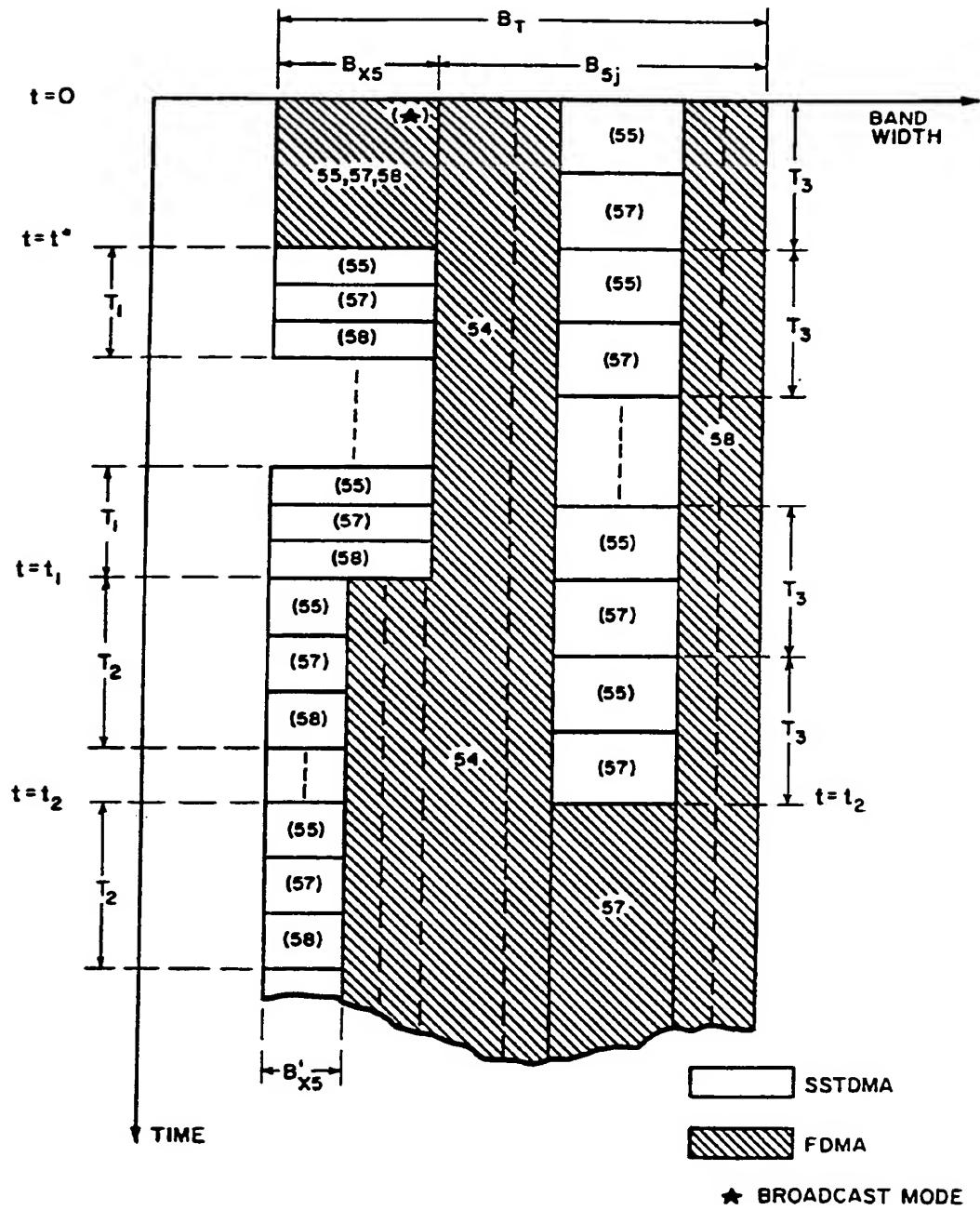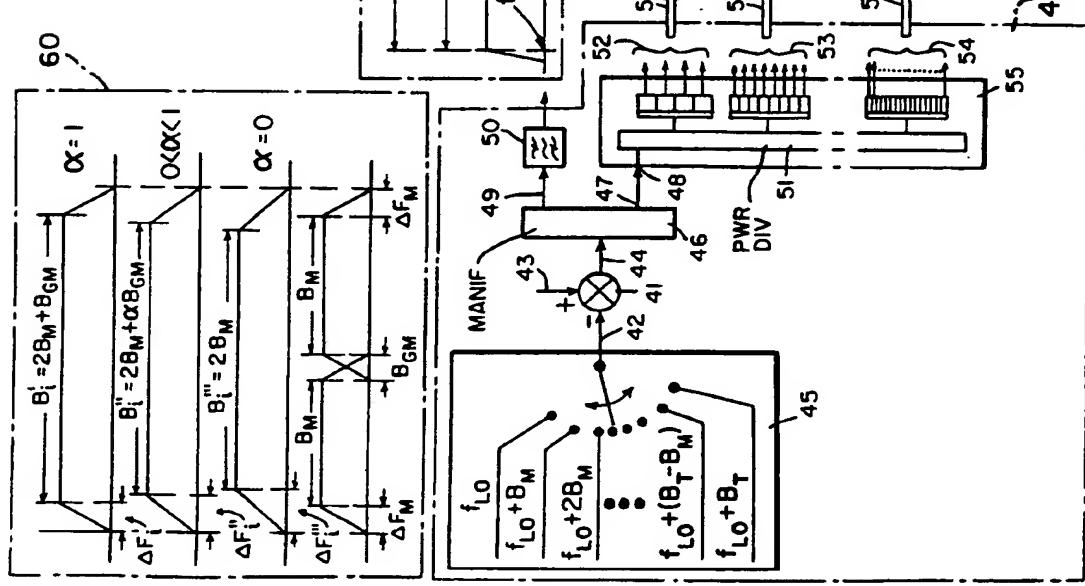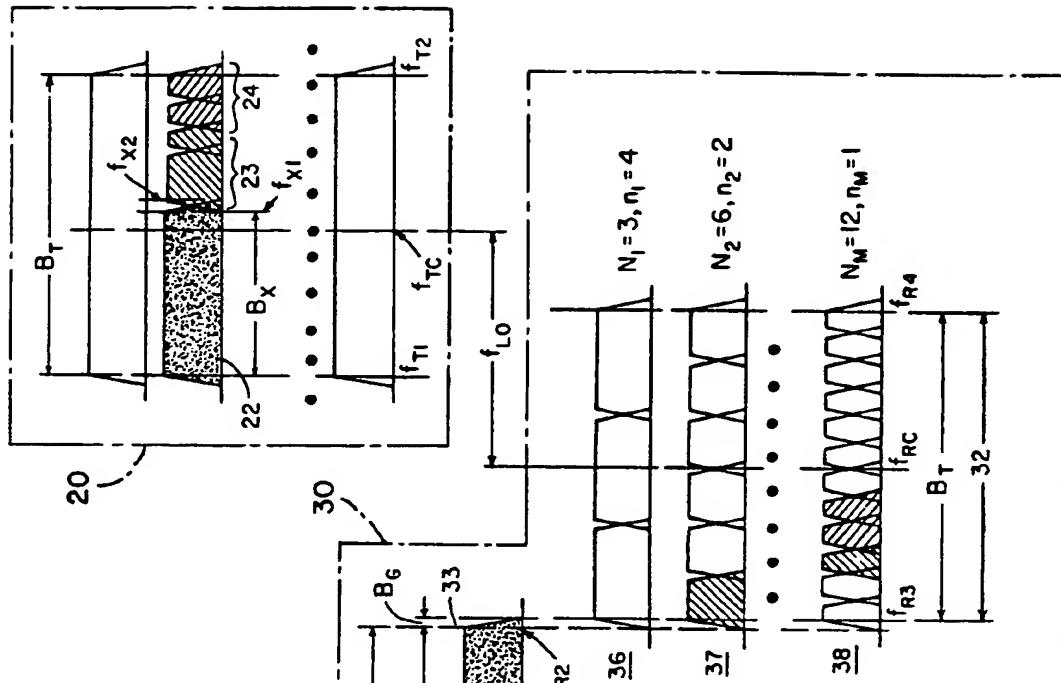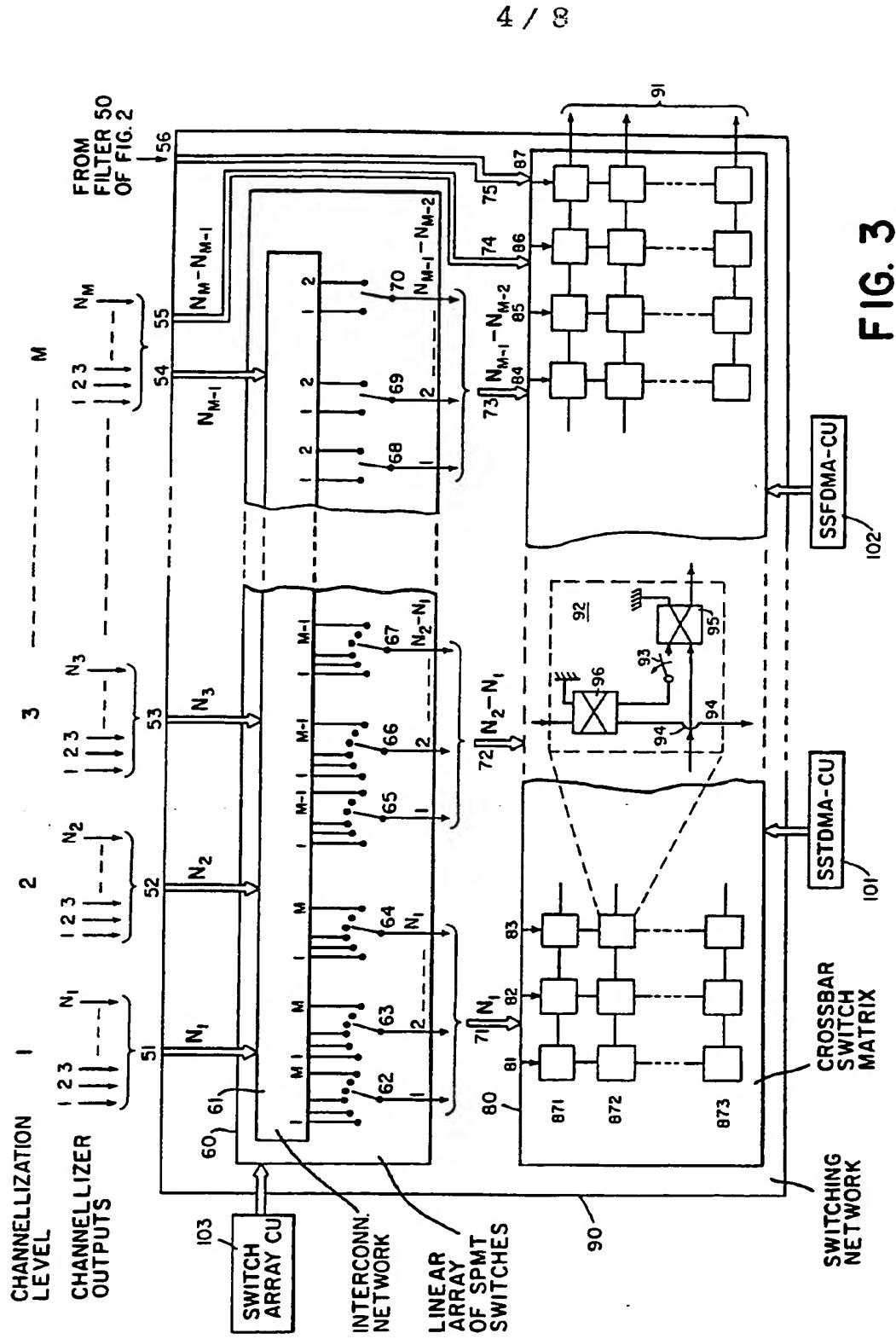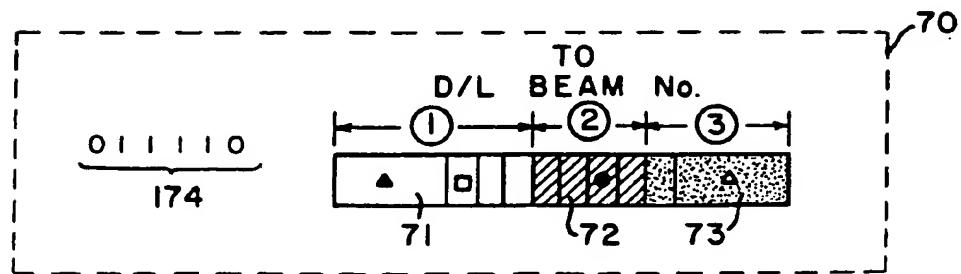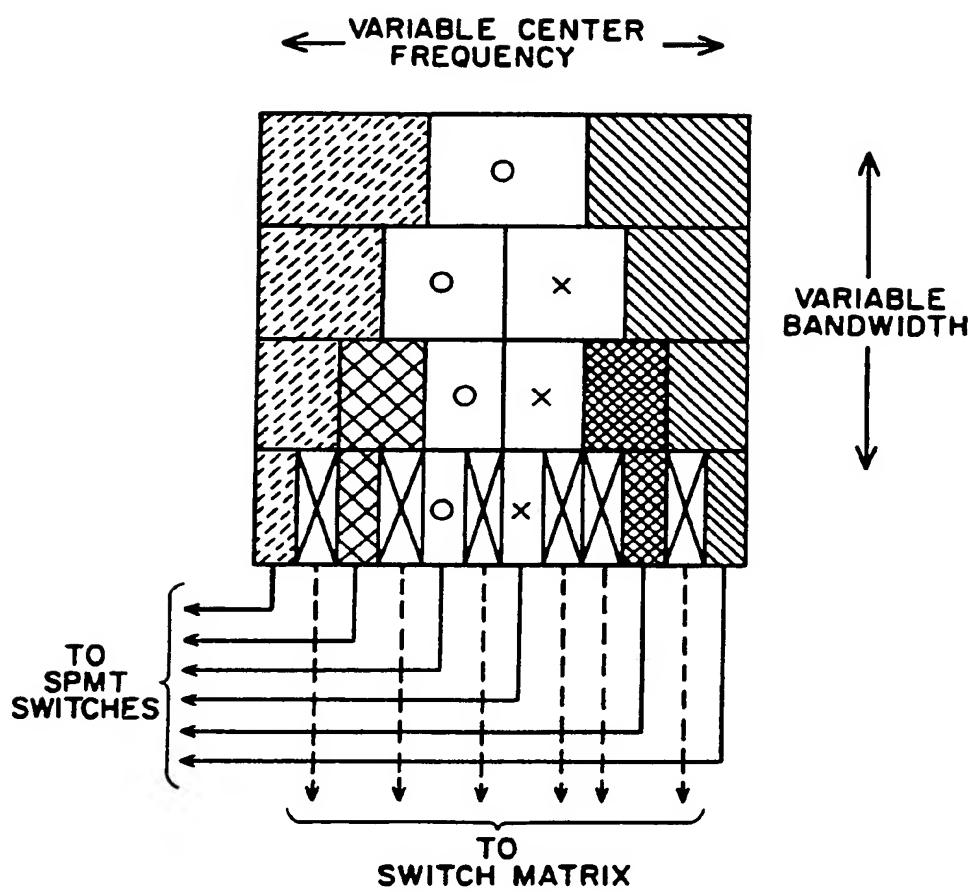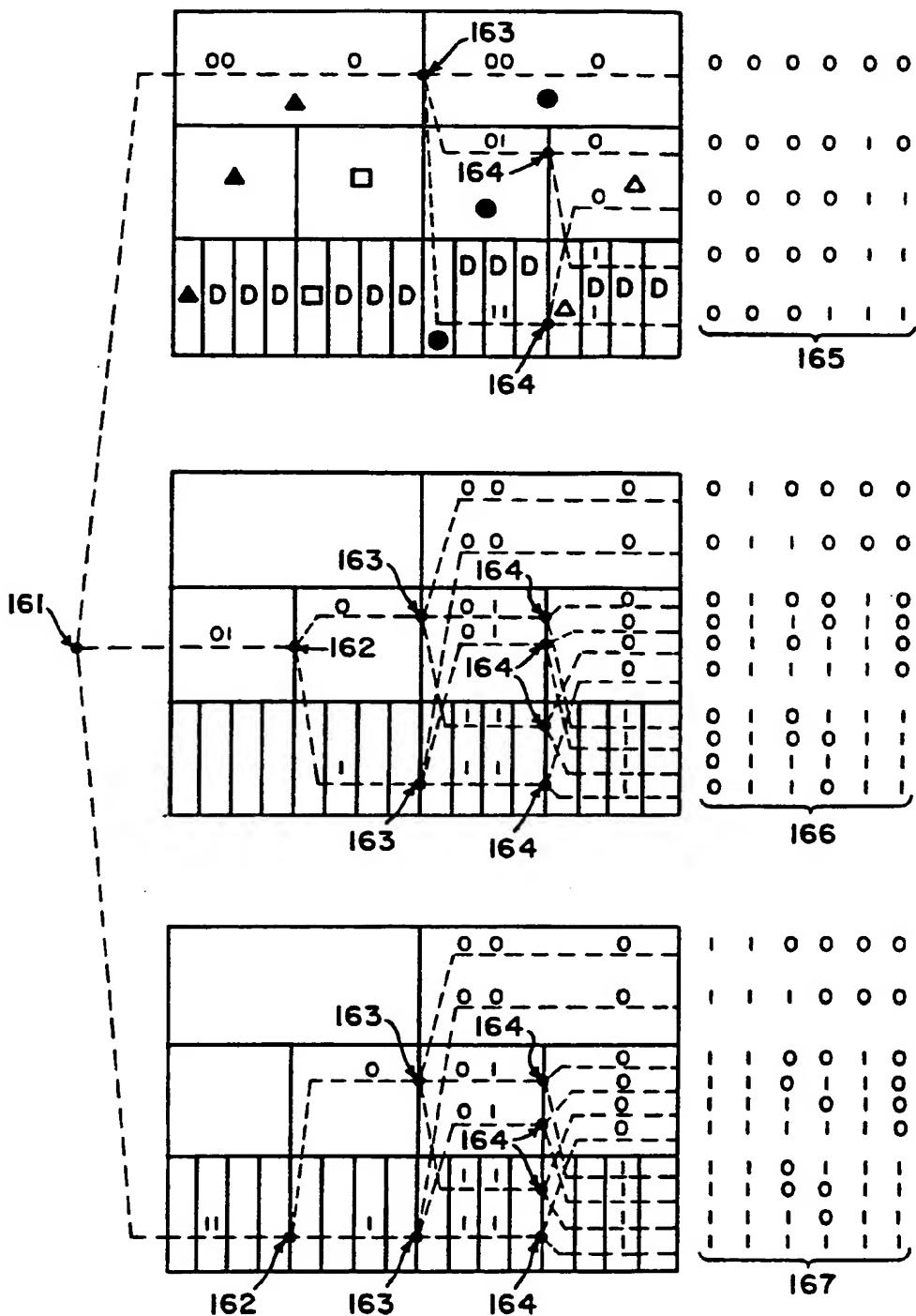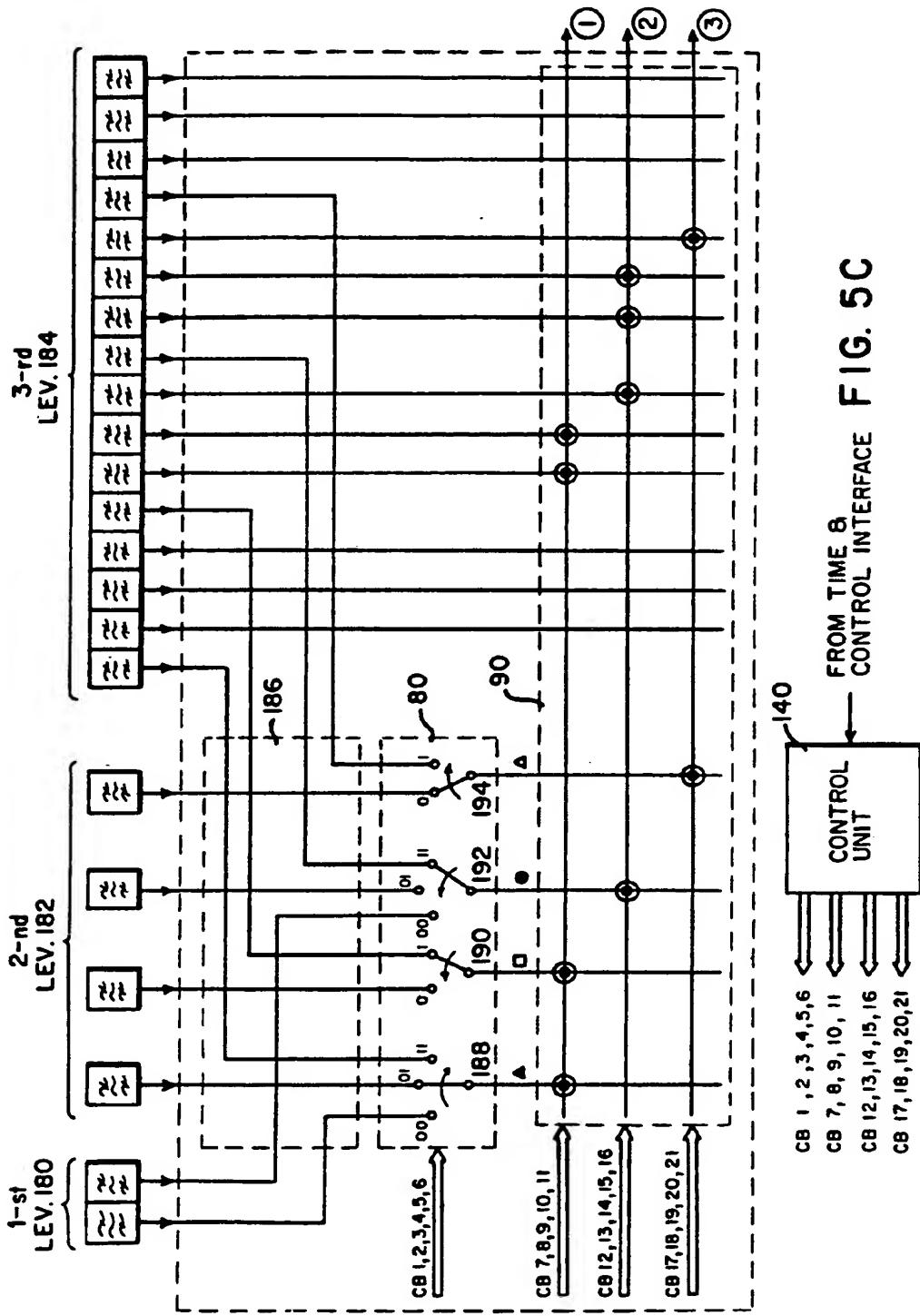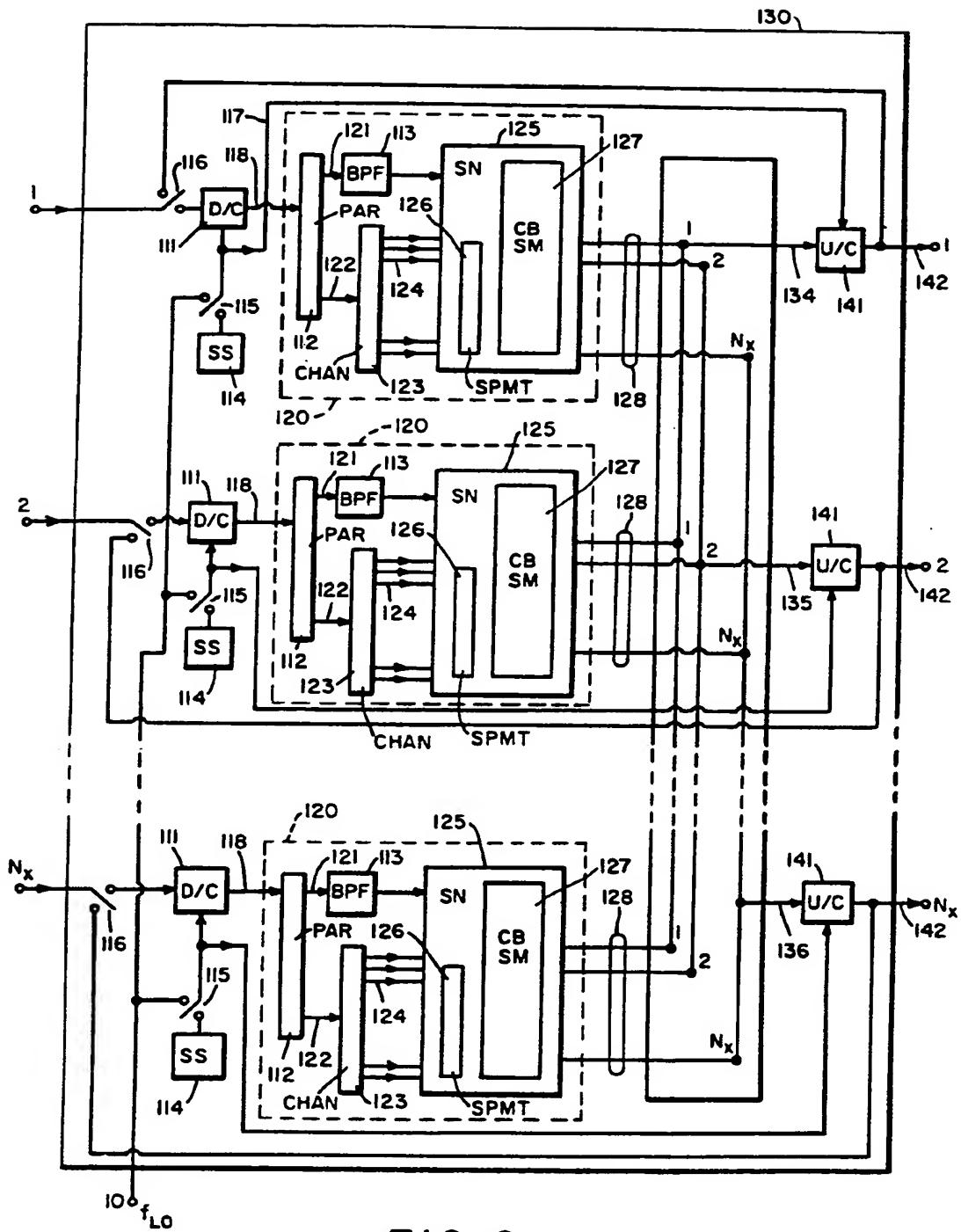

FIG. IA

GB 2 232 560 A

FIG. IA

FIG. IB

FIG. 2

f_{T2}

f_{X2}

24

23

f_{X1}

f_{TC}

B_T

B_X

22

f_{T1}

20

$N_1 = 3, n_1 = 4$

$N_2 = 6, n_2 = 2$

$N_M = 12, n_M = 1$

f_{R4}

f_{RC}

B_T

32

f_{R3}

36

37

38

f_{LO}

30

B_G

33

f_{R2}

31

B_T

f_{R1}

56

57

58

52

53

54

55

50

49

47

48

46

PWR DIV

51

MANIF

43

44

41

42

45

f_{LO}

$f_{LO} + B_M$

$f_{LO} + 2B_M$

$f_{LO} + (B_T - B_M)$

$f_{LO} + B_T$

40

60

$\alpha = 1$

$B_i' = 2B_M + B_{GM}$

$\Delta F_i'$

Δf_M

$0 < \alpha < 1$

$B_i'' = 2B_M + \alpha B_{GM}$

$\Delta F_i''$

$\alpha = 0$

$B_i''' = 2B_M$

B_M

$\Delta F_i'''$

B_M

B_{GM}

B_M

B_{GM}

Δf_M

FIG. 3

FIG. 4

VARIABLE CENTER
←—————— ——————→
FREQUENCY

VARIABLE
BANDWIDTH

TO
SPMT
SWITCHES

TO
SWITCH MATRIX

FIG. 5B

TO
D/L   BEAM   No.

① ② ③

0 1 1 1 1 0

174

71   72   73

70

F I G. 5A

FIG. 5C

FROM TIME &
CONTROL INTERFACE

FIG. 6

VARIABLE BANDWIDTH VARIABLE CENTER-FREQUENCY
MULTIBEAM SATELLITE-SWITCHED ROUTER

Background of the Invention

5   This invention relates to satellite
communications systems, but more specifically, to a
novel method and apparatus for providing on-board
control of reconfiguration of interbeam connections
in accordance with traffic demands in a multibeam
10   communications satellite system.

In present commercial communications
satellite systems operating at 6 and 4 GHz (C-band),
14 and 11 GHz (Ku-band) and 20-30 GHz (Ka Band),
on-board connectivity between uplink and downlink
15   beams is carried out on a transponder channel basis
by providing "static" switching networks with
occasional switch reconfigurations of about fifty to
one hundred times per year. Switching schemes
employed therein are suitable for carrying Frequency
20   Division Multiple Access (FDMA) continuous traffic.
Other satellite systems provide "dynamic" switching
with reconfiguration periods of a few milliseconds
suitable for carrying Satellite Switched Time
Division Multiple Access (SSTDMA) burst traffic.
25   Switching of communications paths between multiple
uplink and downlink beams is usually performed by a
switch matrix on a transponder channel basis. These
on-board switch matrices map input (uplink) traffic
into output (downlink) traffic, wherein switch
30   configurations change only the output port connected
to a given input port without changing the
bandwidths of the respective interconnecting paths.
This connectivity will be hereafter referred to as

Constant Bandwidth ("CB") connectivity and the associated traffic "CB" traffic.

Present-day CB-FDMA communications systems only employ one-to-one static connectivity networks between uplink and downlink co-frequency transponder channels and utilize mechanical coaxial switches requiring no D.C. power to hold them in position after actuation. A typical switching for this application is a "rearrangeable switch matrix" architecture using "beta" elements as building blocks. On the other hand, present-day CB-SSTDMA (constant bandwidth satellite-switched time-division multiple access) communications satellite systems employ connectivity networks between uplink and downlink channels which utilize coupler cross-bar Microwave Switch Matrices (MSM) of either diodes or field-effect transistors (FETs) having rise-fall times of a few nanoseconds. No on-board satellite-switched TDMA systems having variable bandwidths are presently known to exist.

When on-board interbeam connectivity is represented by a matrix with entries corresponding to the bandwidths of the interbeam connection paths, then a CB connectivity function for one group of co-frequency transponder channels in a satellite system (e.g. 8 beams) at a given time instant is represented by an 8x8 matrix having only one non-zero element in each row or column. The following matrix is typical.

DOWNLINK BEAM No.

		1	2	3	4	5	6	7	8
	1	0	B_T	0	0	0	0	0	0
	2	B_T	0	0	0	0	0	0	0
UP-LINK BEAM No.	3	0	0	0	0	0	B_T	0	0
	4	0	0	B_T	0	0	0	0	0
	5	0	0	0	B_T	0	0	0	0
	6	0	0	0	0	B_T	0	0	0
	7	0	0	0	0	0	0	0	B_T
	8	0	0	0	0	0	0	B_T	0

[1]

where B_T is a transponder bandwidth for the respective channels. In SSTDMA systems, channel configuration is represented by the same matrix [1], but the non-zero matrix elements change their location periodically in time. A complete representation of the entire satellite interbeam connections comprises a number of such switch matrices equal to at least the number of transponder channels.

CB connectivity, in conjunction with the ability to steer spot beams over high traffic sources, so far has proven adequate for heavy route traffic with occasional connectivity changes. Also, for thin-route traffic, CB connectivity may be sufficient. For such traffic, on-board connectivity changes are minimal since carriers are somewhat dispersed in space and time.

4

Recently, however, in response to traffic
demands including a relatively large number of small
users, more "intelligent" satellites have been
developed which adaptively achieve high satellite
design efficiencies via narrow interbeam
connectivity paths with reconfigurable bandwidths,
e.g., Variable-Bandwidth, Variable Center-Frequency
(VBVCF) on-board connectivity. Here, satellite
design efficiency is defined as the ratio of
saturation capacity to the nominal capacity of the
satellite, and provides an indication of how
efficiently satellite resources are utilized, such
as, how on-board connectivity and antenna coverage
match traffic demands.

According to an aspect of the present
invention, VBVCF connectivity may be implemented
without increasing the number of on-board TWTAs
(travelling wave tube amplifiers) by subdividing a
transponder bandwidth into a number of narrower
channels of varying bandwidth and accommodating
within the same transponder different thin route
services with different connectivity requirements.
Recent on-board TWTA linearization techniques and
modulation formats make this design philosophy
particularly attractive. As an example, services
requiring a continuous band of variable width may be
assigned upon demand to a sub-band B_x of transponder
bandwidth B_T while the remaining bandwidth B_T-B_x may
be channelized into a multiplicity of narrow VBVCF
channels suitable for multicarrier traffic with a
varying number of different carriers. In its
operation, each channel is subsequently routed to a
defined downlink beam by a switching network.

A circuit that performs VBVCF demultiplexing and routing functions is called herein an "on-board router". Continuous FDMA traffic with on-board VBVCF connectivity achieved

5   either partially or completely by on-board switching networks is called herein "VBVCF Satellite-Switched FDMA (SSFDMA) traffic". In accordance with a further aspect of this invention, existing CB connectivity is enhanced by providing both CB

10   connectivity and VBVCF connectivity within the same spacecraft wherein the VBVCF connectivity is provided by an on-board router to provide satellite-switch capability.

       As discussed herein, prior on-board routers

15   for VBVCF connectivity were proposed as early as 1980, mainly in connection with continuous FDMA traffic. For example, U.S. Patent 4,228,401 entitled "Communication Satellite Transponder Interconnection Utilizing Variable Bandpass Filter"

20   and issued on October 14, 1980 describes a system employing a payload which lacks on-board switching capabilities, but features reconfigurable beam interconnections using VBVCF filters achieved by a serial filter architecture. The VBVCF filter

25   utilized therein performs two successive frequency translations of the signal frequency spectrum with respect to the fixed passbands of two equal filters being serially connected. Unfortunately, this technique, although useful for other applications

30   (see, for example, J. Melngilis and R.C. Williamson, "Filter With Bandwidth Continuously Variable From 5 to 100 MHz", Proc. 1977 Ultrasonics Symp. pp. 965-968), has marginal practical utility for linear phase (constant delay time) communication channels

due to the adding up of transmission amplitude and
phase ripples in the serially connected passband
filters in the vicinity of their upper edge
frequency. On the contrary, in the inventive router

5   described herein, the VBVCF demultiplexing function
is implemented by a switchable combination of
passband filters connected in parallel and does not
suffer from the adding up of spectral impurities
injected by serial filters.

10   The on-board FDMA routers proposed in the
early eighties mainly relate to 30 and 20 GHz
multiple beam satellite systems. At these
frequencies, a large frequency spectrum is available
for commercial satellite communications (2500 MHz

15   times frequency reuse) and, consequently, prior
routers were designed on the basis of broadband   .
channelization schemes which accommodate large
numbers of elementary channels which are frequency-
multiplexed over large bandwidths.

20   Reconfigurability was achieved by sorting out from a
large number of available channels those which
closely match user demands. For narrowband
reconfigurable connectivity, very large filter banks
and switch matrices are present in those routers.

25   Hardware complexity as well as weight and volume
render these routers unattractive and caused a shift
of interest toward alternate on-board routing
solutions such as SSTDMA (Satellite Switched Time
Division Multiple Access).

30   A good summary of on-board SSFDMA router
technologies sponsored by NASA is presented in "A
comparison of Frequency Domain Multiple Access
(FDMA) and Time Domain Multiple Access (TDMA)
Approaches to Satellite Service for Low Data Rate

Earth Stations", G. Stevens, NASA Tech. Memo. 83430,
June 1983. A detailed description of past on-board
FDMA router designs is presented in
"Non-regenerative Satellite Switched FDMA (SSFDMA)
5   Payload Technologies", P. de Santis, International
Journal of Satellite Communications, April-June
1987, Vol. 5, pp. 171-190. Additional information
may also be found in J.D. Kiesling, "Study of
Advanced Communications Satellite Systems Based on
10   SS-FDMA", G.E. Document No. 80SDS4217 NASA Contract
No. NAS-3-21745, May 1980; J.D. Kiesling, "Direct
Access Satellite Communications Using SS-FDMA",
Proc. AIAA 8th CSSC, Orlando, FL, April 20, 1980,
pp. 627-633; and "Customer Premise Service Study for
15   30/20 GHz Satellite Systems", TRW Space and
Technology Group, NASA Contract NAS-3-22889, Final
Report, Document No. 038050-011, April 22, 1982.
In view of the present state of the art of
on-board technologies and the difficulties
20   experienced in prior satellite routing systems in
reconfiguring transponder channels, it is an
objective of the present invention to provide a
practical routing system for improving the
efficiency and flexibility of handling traffic
25   demands.
It is another object of the present
invention to utilize advantageously existing on-
board CB switching networks to enhance traffic
handling capabilities thereof.
30   It is a more specific object of the present
invention to provide a system for reconfigurably
dividing a transponder bandwidth into at least two
sub-bands of variable width wherein at least one

sub-band is further channelized to achieve multiple VBVCF subchannels.

It is a further object of the present invention to provide a system for routing traffic through a demultiplexer with linear phase VBVCF channels which utilizes a "parallel" architecture and is based on a class of multi-level channelization formats preferably implemented by time and frequency multiplexing circuits.

It is yet a further object of the present invention to provide an on-board router with programmable routing of sub-channels to downlink beams wherein each subchannel may accommodate either burst traffic (SSTDMA) or continuous traffic (SSFDMA).

Summary of the Invention

Aspects of the invention are realized by a method and apparatus wherein CB connectivity enhancement is preferably carried out by a device, such as an on-board router, in conjunction with an existing CB connectivity network on board a multibeam communications satellite employing multiple transponder channels. Both CB and VBVCF traffic are beamed to the satellite in uplink beams of given bandwidths and center frequencies. Upon receipt, the bandwidth of each uplink beam is divided into a number of transponder channels of bandwidth B_T. The transponder channels carrying VBVCF traffic are further partitioned in a number of sub-transponder channels by the on-board router. Of these channels, one provides a continuous band of variable width which is particularly suitable to SSTDMA traffic with variable burst rate.

The method and apparatus can be appreciated with reference to matrix [1] above and assuming VBVCF traffic exists in uplink beams 5, 6, 7 and 8 and downlink beams 4, 5, 7 and 8. The enhanced CB connectivity matrix [2] is as follows:

DOWNLINK BEAM No.

		$j =$	1	2	3	4	5	6	7	8	
	$i =$	1	0	B_T*	0	0	0	0	0	0	
		2	B_T*	0	0	0	0	0	0	0	
UP-LINK BEAM No.		3	0	0	0	0	0	B_T*	0	0	
		4	0	0	B_T*	0	0	0	0	0	[2]
		5	0	0	0	B_{X5}	B_{55}	0	B_{57}	B_{58}	
		6	0	0	0	B_{64}	B_{X6}	0	B_{67}	B_{68}	
		7	0	0	0	B_{74}	B_{75}	0	B_{77}	B_{X7}	
		8	0	0	0	B_{84}	B_{85}	0	B_{X8}	B_{88}	

where "*" entries represent CB traffic and the other entries represent VBVCF traffic. Connectivity paths with bandwidths B_T* are established by a CB connectivity network while paths B_{ij} (i = 5,6,7,8 and j = 4,5,7,8) and B_{xi} (i = 5,6,7,8) are established in the on-board router. In matrix [2], bandwidth B_{xi} is a fraction of a transponder bandwidth B_T, while B_{ij} are fractions of the remaining $B_T - B_{xi}$.

$$\Sigma_j \quad B_{ij} \quad \le \quad B_T \quad - \quad B_{xi}$$

[3]

VBVCF reconfigurability is accomplished by changing the values of the entries B_{xi}, B_{ij}.

A preferred method to enhance CB traffic in an existing on-board CB network is carried out by interfacing a device, such as an on-board router, with the CB network. The preferred method further includes the steps of dividing the transponder bandwidth into two parts wherein one part is further channelized establishing respective bandwidths and center frequencies of the elementary VBVCF traffic channels, re-routing the VBVCF traffic through the CB network to downlink beams, and controlling the center frequencies and bandwidths (e.g. values of Bxi and B_{ij}) of the VBVCF channels.

According to the apparatus of the invention, an on-board router is serially connected to and operates simultaneously with CB networks existing on-board the spacecraft. The router includes means to receive VBVCF traffic of given bandwidths and center frequencies, means to partition a transponder bandwidth into at least two sub-bands, means to channelize further at least one of the sub-bands to establish a plurality of elementary channels that carry the VBVCF traffic, and switching means to translate or map uplink to downlink paths within the router and CB network. The bandwidths and center frequencies of the elementary VBVCF channels may be controlled externally.

The system accommodates CB and VBVCF traffic wherein the CB traffic requires constant

bandwidth connectivity with occasional
reconfigurations and the VBVCF traffic requires
variable bandwidth connectivity.

These and other objects, aspects and
5   features of the invention will become apparent to
those skilled in the art upon consideration of the
following description of the illustrative
embodiments taken in connection with the
accompanying drawings. The invention though is
10   pointed out with particularity by the appended
claims.

Brief Description of the Drawings
Figs. 1A is a block diagram of a preferred
on-board router in accordance with the present
15   invention coupled with a typical CB connectivity
network of a satellite. Illustrative uplink and
downlink frequency plans also are shown.

Fig. 1B is a conceptual depiction of
bandwidth configuration versus time characteristics
20   of channel routing achieved by the on-board router
of Fig. 1A.

Fig. 2 depicts the input section 40 of the
on-board router of Fig. 1A, and conceptually shows
an uplink frequency plan 20 relative to a group of
25   co-frequency transponders in an N-beam
communications satellite, a channelization plan 30
achieved by the on-board router for routing through
the CB connectivity network, and a preferred band-
splitting scheme 60 required to achieve the
30   principles of the present invention.

Fig. 3 shows a schematic block diagram of a preferred switching network incorporated in the on-board router of Fig 1A, and also depicts the details of one element of the crossbar switching matrix of Fig 3.

Fig. 4 conceptually illustrates the basic design philosophy of the switching network contemplated by the present invention.

Figs. 5(a) through 5(c) illustrate a practical example channel routing and controlled switching in the on-board router of Fig. 1A.

Fig. 6 is a block diagram of a preferred on-board router according to the present invention.

Description of Illustrative Embodiments

Referring to Figs. 1A and 1B, an on-board router 10 couples with an existing on-board CB connectivity network 12 to achieve CB connectivity enhancement. The router 10 and CB network 12 are located on board a communications satellite and provide reconfigurable interconnection paths between uplink and downlink beams in accordance with exemplary frequency plans 11 and 13, respectively. These paths may carry digital traffic from digitized telephone voice signals and/or data communications systems requiring varying rates of data transmission, as well as varying volumes of analog FM traffic. Further, these paths may accommodate either FDMA or TDMA traffic in accordance with the present invention. As previously indicated, CB refers to Constant Bandwidth transponder traffic

whereas VBVCF refers to Variable Bandwidth Variable Center Frequency sub-transponder traffic. The widths of the rectangles within the blocks of frequency plans 11 and 13 generally indicate the bandwidth requirement of the traffic along a specific path. Continuous and dashed lines correspond to CB and VBVCF traffic, respectively. For example, the first four blocks of uplink frequency plan 11 indicate CB traffic, occupying the entire transponder bandwidth B_T whereas the rectangles in the latter four blocks of plan 11 respectively indicate bandwidth requirements of VBVCF traffic in each of the four channels 5-8.

Uplink frequency plan 11 shows a possible transponder channelization according to the previously defined enhanced connectivity matrix [2]. By transponder frequency plan, it is meant a given division of transponder frequency band into a set of sub-bands corresponding to various traffic paths. In each block of plan 11, the two digits in each pair represent respectively the numerical identity of the origin and destination beams as also indicated at the respective inputs and outputs of router 10 and CB network 12 in Fig. 1A. Likewise, downlink frequency plan 13 depicts the character of the downlink channels and also indicates the translated path sequences by origin and destination beam number. More than one pair of digits within the same rectangle indicates that a particular bandwidth is utilized for a multiplicity of interconnection paths. Digit pairs within parentheses refer to SSTDMA traffic, whereas digit pairs without parentheses refer to FDMA traffic.

14

According to the present invention,
frequency plan 13, on the other hand, shows typical
satellite-switched interbeam connections and
translations for both CB and VBVCF traffic. Uplink
beams 1-4 handle CB traffic routed through CB
connectivity network 12, while uplink beams 5-8
handle VBVCF traffic routed through the network 12
and the router 10. The router 10 connects in
series and simultaneously operates with the static
connectivity network 12. It also partitions VBVCF
traffic and routes VBVCF traffic to the appropriate
downlink beams.

For purposes of illustration, the router
10 comprises a VBVCF filter connected in parallel
with an internal multistage channelizer (MSC)
defined in connection with Fig. 2. The MSC is
connected to a coupler crossbar switching network
controlled by SSTDMA controller 14 and SSFDMA
controller 16. Switches in any row of the switch
matrix may be activated according to either a
periodic time pattern typical of SSTDMA applications
(burst traffic) or a reconfiguration time plan
typical of SSFDMA applications (continuous traffic),
respectively, utilizing either the SSTDMA controller
14 or the SSFDMA controller 16. Switching points
shown in the router 10 controlled by the SSTDMA
controller 14 are depicted as open circles, while
switching points controlled by the SSFDMA controller
16 are depicted as black dots. This configuration
of the switch matrix exists for a given instant of
time. At a different time instance, switch
controllers 14 and 16 may effect other switch
configurations.

Fig. 1(B) is a bandwidth-versus-time representation of a hypothetical channelization plan relative to traffic originating from uplink beam no. 5. Digit pairs in Fig. 1(B) representing origin/destination paths correspond to digit pairs shown in Fig. 1(A). Subchannel division also corresponds. At time $t = 0$, the bandwidth B_{x5} is initially utilized by an SSFDMA broadcast mode through paths [55], [57], [58] wherein traffic originates in beam 5 and is simultaneously broadcast to downlink beams 5, 7 and 8. At time $t = t*$, the operation mode changes into an SSTDMA mode with a frame duration of T_1. Within each frame T_1, information in subchannel B_{x5} is time-multiplexed through respective paths [55], [57] and [58]. At time $t = t_1$, a router reconfiguration occurs whereby the bandwidth B_{x5} allocated to paths [55], [57] and [58] in the SSTDMA mode shrinks to $B'x_5$, and concurrently, the frame duration changes from T_1 to T_2, wherein the multiplexed intervals enlarge. The bandwidth $(B_{x5}-B'_{x5})$ is now utilized to widen the bandwidth of the [54] interconnection path for carrying SSFDMA traffic. Another reconfiguration occurs at $t = t_2$. In this case, no bandwidth variation occurs, but the [55] and [57] SSTDMA mode paths with a frame period T_3 are changed into a continuous SSFDMA mode path [57] with the same bandwidth.

No CB traffic switching occurs within the router 10. CB traffic is switched only by the static connectivity network 12 and VBVCF traffic is independently switched by the router 10. Consequently, CB and VBVCF traffic switching may utilize different technologies in accordance with

the different requirements of the two types of traffic.

Router 10 includes switch matrices and control means for independently routing the respective incoming traffic to specific downlink beams through the network 12. It also includes filter banks for channelizing a portion of a transponder channel at controllable bandwidths and center frequencies thereby establishing narrow band paths for the elementary channels of VBVCF traffic. Preferably, these filter banks have bandpass characteristics with high skirt selectivity. Skirt selectivity in dB/MHz is defined here as the ratio of 39dB to the 1-40dB transition bandwidth, i.e. the difference between the 40dB bandwidth and the 1dB bandwidth divided by two.

Fig. 2 shows the input section of the router 10 and illustrates a typical frequency partitioning of one of the eight transponder channels. A description of one such channel is exemplary of the remaining transponder channels. Fig. 2 shows an ideal transponder uplink frequency plan 20 relative to a group of co-frequency transponders in an N-beam satellite communications system, an exemplary frequency plan 30 implemented by the on-board router 10, and a band-splitting scheme 60 utilized for achieving the goal of the present invention. A typical satellite communications system includes several such groups of transponders for relaying traffic information among beams. In frequency plans 20 and 30, each traffic channel is ideally represented by a trapezoid whose upper and lower sides demarcate the useful (e.g. 1dB) and the 40dB bandwidth. The

distance between the upper sides of two adjacent
trapezoids will be hereafter referred to as the
guardband B_G.

A transponder's center frequency is
defined as $f_{TC} = (f_{T1} + f_{T2})/2$ where f_{T1} and f_{T2} which
are the lower and upper edge frequencies, define the
1dB attenuation points, respectively. As an
example, single carrier, variable bit rate traffic
in uplink plan 20 occupies a useful bandwidth B_x 22
from f_{T1} to f_{x1} while multicarrier traffic occupies a
bandwidth $B_T - B_x$ from f_{x2} to f_{T2}. In this example,
multicarrier traffic is assigned to two connectivity
paths 23 and 24 each containing traffic destined to
the same downlink beam.

The on-board router frequency plan 30
preferably consists of two fixed adjacent passbands
31 and 32 whose useful bandwidths extend from f_{R1} to
f_{R2} in passband 31, and from $f_{R3} = (f_{R2} + B_G)$ to f_{R4} in
passband 32. Passbands 31 and 32 need not be
adjacent, but preferably are so to efficiently
utilize the total bandwidth of the transponder
channel. Shaded areas in passbands 31 and 32
correspond to beam No. 2 traffic 22, 23, and 24,
respectively. Passband 31 is allocated to single
carrier traffic and is provided by a fixed bandpass
filter with very high skirt selectivity to achieve
high spectrum utilization. It is assumed that the
1dB - 40dB transition bandwidth 33 at the upper edge
frequency f_{R2} equals the guardband B_G associated with
the M-th channelization level of passband 32. Under
these circumstances, the adjacent channel
interference (ACI) between single carrier and
multicarrier traffic is suppressed more than 39dB.
The center frequency of passband 32 is $f_{RC} = (f_{R3}+$

$f_{R4})/2$. It is referred to hereafter as the "router
center frequency" whose choice is mainly dictated by
the technology utilized for implementing the
router's filters.

As a further constraint for implementing
the exemplary plan of Fig. 2, $f_{R2}-f_{R1} = f_{R4}-f_{R3} = B_T$.
B_T represents the largest value needed for $f_{R4} - f_{R3}$
to accommodate any value of $0 \leq B_X \leq B_T$. In
practice, assuming a minimum loading factor
$LF_{min} = 100\ B_{X,min}/B_T$ for single carrier traffic, then
this inequality becomes:

$$B_{X,min} = (LF_{min}B_T)/100 \leq B_X \leq B_T \qquad [4]$$

and

$$f_{R4} - f_{R3} = B_T - B_{X,min} \qquad [5]$$

As an example, if $LF_{min} = 50\%$

$B_{X,min} = B_T/2$ and

$$f_{R2} - f_{R1} = B_T \qquad [6]$$

$$f_{R4} - f_{R3} = B_T/2 \qquad [6']$$

Passband 32 is reused M times by M
filterbanks in the router 10. The M filterbanks are
connected in parallel to avoid additive distortion
typical in serially connected filters. Each
filterbank constitutes a "stage" of a multi-stage
"parallel" channelizer and implements a
channelization "level" of the multi-level
channelization plan. In essence, each filter bank
channelizes bandwidth 32 into a number of elementary
VBVCF channels. In each stage, the elementary

channels differ by their center frequency and may
have equal or different useful bandwidths,
transition bandwidths and guardbands. According to
one arrangement, the N_i passband filters at the i-th

5   channelizer stage have the same nominal values of
bandwidth B_i, guardband $B_{G,i}$ and 1-40 dB transition
bandwidth F_i in order to minimize hardware
complexity. The channelization level with the
smallest number N_1 of elementary channels will be

10 hereafter referred to as the lowest level. The
channelization level with the highest number N_M of
elementary channels will be referred to as the
highest level.

      For the case where two adjacent channels

15 separated by two passband filters have the same
insertion loss at their edge frequencies and the
guardband between them is B_G, then in a given
channel, the maximum adjacent channel interference
ACI_{max} (namely the minimum C/I if C is the desired

20 signal power and I is the interference signal power)
caused by an adjacent channel with a lower center
frequency is equal to the increment of the adjacent
channel insertion loss associated with an increase
of B_G in the upper edge frequency. If the adjacent

25 channel has a higher center frequency, ACI_{max} is
equal to the increment of the adjacent channel
insertion loss associated with a decrease of B_G in
the lower edge frequency.

      In the present invention, the preferred

30 channelization plans satisfy the following property.
Frequency-division multiplexing of elementary
channels selected from different channelization
levels generate a VBVCF channel sequence wherein
$(ACI)_{max}$ between two channels, is smaller than a

specified value or, alternatively, $(C/I)_{min}$ between
any two channels is larger than a specified value.
A mathematical formulation of the above property is
indicated below.

5   (1) The useful (i.e. 1dB) bandwidth to be
channelized is completely filled by an integer
number N_M of elementary channels of bandwidth B_M plus
an integer number (N_M-1) of guardbands B_{GM}, namely:

$$B_T = N_M B_M + (N_M - 1) B_{GM} \qquad [7]$$

10

(2) With reference to the router frequency
plan 30 of Fig. 2, letting $F_M = B_{GM}$ and n_i (integer)
$= N_M/N_i$, the condition that one i-th level channel
may replace n_i channels of the M-th level requires:

$$B_i + 2 F_i = n_i B_M + (n_i-1) B_{GM} + 2B_{GM} . \qquad [8]$$

15   More in general, equation [8] may be recast in
parametric form:

$$B_i = n_i B_M + \alpha(n_i-1)B_{GM} \qquad [9]$$
$$F_i = B_{GM} [1 + \alpha + n_i (1- \alpha)]/2 \qquad [10]$$

20

utilizing a parameter $0\leq \alpha \leq 1$ to be chosen on the
basis of available resources (e.g. frequency
spectrum and filter technology) as well as system
25   requirements. Spectral graphs 60 of Fig. 2
represents a portion of a channelization format with
$n_i = 2$ for the three cases of $\alpha = 0$, for $0 < \alpha < 1$,
and $\alpha = 1$. For $\alpha=1$, transition bandwidth is minimal
thus providing more useful bandwidth for carrying
30   information.

(3) The condition that $(C/I)_i$ between any two
adjacent channels at the i-th level is larger than a
minimum value $(C/I)_{min}$ requires that:

$$B_{Gi} = 2 F_i - B_{GM} = B_{GM} [\alpha + n_i (1 - \alpha)][11]$$

Channelization formats which satisfy
equations [7] through [11] and have different values
of the parameter α differ from one another by
channel shape factors ($SF_i = 1 + 2\ F_i/B_i$), spectrum
utilization efficiency ($_i = 100\ N_iB_i/B_T$) and adjacent
channel interference $(C/I)_i$. For example, the
channelization format 30 of Fig. 2 ("brickwall"
format) provides maximum $_i$ and satisfies the
condition $\alpha = 1$, so that, from equations [10] and
[11]:

$$B_{Gi} = F_i = F_M = B_{GM} \qquad [12]$$

For $N_M = 12$, a brickwall channelization
format has five possible levels as shown in the
following table [13]:

[13]

CHANNELIZATION LEVEL	N_i	n_i	$\alpha = 0$		$\alpha = 1$	
			SF_i	η_i	SF_i	η_i
$i = 1$	2	6	1.291	88.88	1.069	98.30
2	3	4	1.312	85.71	1.105	96.81
3	4	3	1.333	84.21	1.143	94.91
4	6	2	1.375	82.75	1.222	91.52
$M = 5$	12	1	1.500	81.30	1.500	81.30

having assumed $B_{GM}/B_M = .25$ namely $SF_M = 1.5$. In Fig. 2, the channelization levels shown correspond to above levels $i = 2, 4$ and 5. From Table [13], it is apparent that a consequence of the $\alpha = 1$ condition is a decrease in SF_i and an increase in $_i$ as the elementary channel bandwidth B_i increases (e.g., lower channelization levels). A decrease of SF_i to values too close to unity (ideal rectangular box filter) might pose severe technological problems in a practical realization of such filters at the lower channelization levels. For this reason, other channelization formats may be considered, e.g. with smaller values of the parameter α. In general, for $0 \leq \alpha \leq 1$,

$$SF_i = 1 + \frac{n_i + 1 - \alpha\,(n_i - 1)}{n_i\,(B_M/B_{GM}) + \alpha\,(N_i + 1)} \qquad [14]$$

As an example, for $\alpha = 0$, table [13] shows $SF_1 = 1.291$ (as compared to $SF_1 = 1.069$ for $\alpha = 1$). Unfortunately, higher shape factors determine lower spectrum utilization efficiencies. An optimum solution results from a trade-off among SF_i, $_i$ and ACI_i requirements.

A description of the router's input section 40 is now made with reference to Fig. 2. Router input section 40 includes an input downconverter 41, a paralleling circuit 46 with one input port and two output ports which couple in parallel a bandpass filter 50 having the transmission characteristic of passband 31, and a

channelizer 55 for developing the subchannels in passband 32. The downconverter 41 is a conventional circuit that frequency-translates a given frequency band from a given center-frequency to a lower center-frequency and may be implemented by conventional circuits known in the art, e.g. a frequency mixer followed by a filter. A paralleling circuit that parallels two bandpass filtering circuits, such as the bandpass filter 50 and the channelizer 55 with minimum insertion loss between the input and output ports, may be implemented by conventional means in a number of ways depending on how the router filters are constructed. For example, it may be constructed of two serially connected three-port circulators with one port terminated on a matched load, if the filters operate at microwave frequencies; or it may be constructed by a constant-k ladder network if the filters operate at Surface Acoustic Wave (SAW) frequencies. See, for example, D.C. Webbs and C. Banks, "Properties of a Constant-K Ladder SAW Contiguous Filter Bank", IEEE Trans. on Sonics and Ultrasonics, Vol. SU-23, No. 6, pp. 386-393, Nov. 1976.

The channelizer 55 includes a 1:M power divider 51 which divides incoming power within passband 32 into M parallel branches including M filter banks 52, 53 and 54. If needed, any power dividing loss $10 \log_{10} M$ (dB) may be either partially or totally offset by linear amplifiers. The router input section 40 also includes a synthesized frequency source 45 which generates a local oscillator frequency $f_{LO} + B_X$, with $f_{LO} = f_{TC} - f_{RC}$, and B_X varies between zero and B_T in discrete steps of width $B'_M = (B_M + B_G)$. Preferably, a crystal source

with a divide-by-n counter is employed to achieve frequency stability although other types of stable sources may be employed.

If a minimum loading factor LF_{min} is assumed, then B_X varies within the interval $B_{X,min} < B_X < B_T$. The input traffic signal is applied to port 43 of the downconverter 41 and simultaneously a local oscillator signal of frequency $f_{LO} + B'_X$ (where $B'_X = B_X + B_G$) is applied to the downconverter via port 42. Downconverter 41 translates f_{X1} onto f_{R2} according to the relationship $f_{X1} - (f_{LO} + B'_X) = f_{R2}$. In this way, all single carrier traffic remains within passband 31 while all multicarrier traffic is within passband 32. Traffic within the bandwidth 32 emerges from port 47 of the paralleling circuit 46. Output 47 is connected to the input 48 of the 1:M power divider 51 which feeds the incoming signals to the M filterbanks 52, 53, 54. Filterbank 52 implements the lowest channelization level and generates N_1 outputs 56 of bandwidth B_1. Filterbank 53 implements the next highest channelization level and generates N_2 elementary channels 57 of bandwidth B_2. The last filterbank 54 implements the highest channelization level M and generates N_M elementary channels 58 of bandwidth B_M. Outputs 56, 57 and 58 are applied to the input ports of a switching network in the router 10 described below in connection with Fig. 3. Although three stages are described to implement the M channelization levels, the invention is not limited to three stages.

Fig. 3 shows a schematic block diagram of a switching network 90 which couples to the bandpass filter 50 (Fig. 2) as well as to the channelizer 51 (Fig. 2) of Fig. 2 in order to switch the M outputs

56, 57, 58 (Fig. 2). In operation, network 90
performs i) selection of any elementary channel from
any channelization level; ii) multiplexing the
selected channels by FDM (frequency-division
multiplexing) techniques, and iii) routing the
channel groups formed in ii) to the desired downlink
beams. The channelization format 30 (Fig. 2) and,
in general, channelization formats satisfying
equations [7] - [11] allow the switching network 90
to perform the two functions indicated by Fig. 4,
namely (a) to connect one-out-of-many input signals
with overlapping bands to a single output port, at
successive instants of time, and (b) to connect
simultaneously plural input signals with
non-overlapping bands to a single output port.
Network 90 is preferably implemented by using two
multiport switching networks performing these
respective functions, hereafter referred to as
switching networks 60 and 80.

Switching network 60 (Fig. 3) is
implemented by a linear array of single pole
multi-throw (SPmT where $m = 2,3,4...M$) switches 62-
70 connected to the channelizer outputs 51, 52, 53,
and 54 via an interconnection network 61. The
switches 62-70 may advantageously be operated and
controlled by a control unit 103 in a conventional
manner by a microprocessor or mechanical means on
board the satellite or automatically in response to
earth command signals, or by other means known in
the art.

Switching network 80 preferably comprises
a crossbar switch matrix with ($N_M + 1$) columns 81,
82, 83, 84, 85, 86, 87 and N_X rows 871, 872, 873, N_X
being the number of down-link beams. The individual

switch matrix crosspoints of the switch matrix 80
are able to provide both "broadcast" (one input to
many outputs) and "report" (many inputs to one
output) mode of operation. For example, they may be
of the type shown in the insert of Fig. 3 with a
SP1T switch 93, a crossover 94 and two directional
couplers 95 and 96. This is a traditional
architecture presently used in many on-board
microwave switch matrices. See, for example, P.T.
Ho, et al. "Coupler Crossbar Microwave Switch
Matrix", Proceedings IEEE-MTT Symp. June 1982, pp.
239-241. Each crossbar switch matrix column may be
controlled either by one of two control units (CU),
SSTDMA controller 101 or SSFDMA controller 102,
which is capable of providing signals for fast
periodic reconfigurability (SSTDMA) or aperiodic
reconfigurability (SSFDMA). The N_x outputs 91 of the
switch matrix 80 emanate from the SPmT switch array
60 at the connection points 71, 72, and 73, or
directly from the channelizer 55 (Fig. 2) at the
connection point 74 and from the passband filter 50
of Fig. 2 at the interconnection 75.   Fig. 4
illustrates the philosophy of the channelizer
connections for an exemplary situation.

         With the aid of Fig. 4, it is understood
that the switching network 90 of Fig. 3 has the
capability to couple one-out-of-many input signals
with overlapping bands to a single output port at
successive instants of time, and/or to connect
simultaneously plural inputs with non-overlapping
bands to a single output port. It shows a
channelization format with $N_1 = 3$, $N_2 = 4$, $N_3 = 6$ and
$N_M = N_4 = 12$. Bands illustrated with the same
graphical markings are switched by the same SPmT

switch with the exception of the 4-th level bands
with crossed bars which are for traffic directly
connected to the crossbar switch matrix 80 of Fig. 3
at the input port 74. Partitioning of bands into
groups switched by the same SPmT switch has been
made according to a criterion of minimum number of
switches. It is, however, recognized that different
criteria may be adopted, e.g. minimizing the number
of throws in each switch.

From the example of Fig. 4, it is apparent
that application of this criterion leads to a
switching network with three SP4T, one SP3T, two
SP2T switches and that six filters out of twelve in
the 4-th channelizer stage directly connect to the
switch matrix. More in general, application of the
criterion of minimum number of switches, generates
the following features which are apparent in Fig. 3.
The input to the switching network 90 from the M-th
filter bank splits into two groups of elementary
channels 54 and 55: a group of N_{M-1} channels goes to
the SPmT switch array 60 and the remaining N_M-N_{M-1}
channels go directly to some input ports 74 of the
crossbar switch matrix 80. The structure of the
SPmT switch array 60, as shown in Fig. 3, is as
follows:

Number of Switches	Switch Type
N_1	SPMT
$N_2 - N_1$	SP (M-1)T
$N_3 - N_2$	SP (M-2)T
. . .	. . .
$N_{M-1} - N_{M-2}$	SP2T
Total: $\quad N_{M-1}$	

[15]

From Table [15] it is apparent that N_{M-1} determines the total number of SPmT switches, M and N_1 control the complexity and the number of the largest SPMT switches. The size of the crossbar switch matrix 80 is determined by N_M and N_X.

Fig. 5(a) illustrates a mechanism to identify and label all possible VBVCF channel sequences which may be generated by a given channelizer. For purposes of illustration, a channelization format with $N_1=2$, $N_2=4$, $N_M=N_3=16$ has been chosen.

Fig. 5(b) depicts a channelization sequence which, as an example, has been chosen to be implemented.

Fig. 5(c) is a circuit diagram of a switching network of the type shown in Fig. 3, with switch settings appropriate for generating the channelization scheme shown in Fig. 5(b).

In Fig. 5(a), sequence labeling is made utilizing a trellis diagram superimposed on the channelization plan of the channelizer. A binary numerical representation is adopted which is suitable for implementation by digital control

signals. Control signals are generated by control
units such as the units 101, 102 and 103 of Fig. 3.
In Fig. 5(a), each possible VBVCF channel sequence
is identified by a path within the trellis diagram
5   represented by dashed lines (branches) and black
dots (nodes). Each branch is associated with the
channels underneath and each node represents an
·option to choose among channels at different levels.
Starting from the node 161, the VBVCF channel
10   sequence may be initiated either by a wide channel
of the first level (branch 00), a medium sized
channel of the second level (branch 01), or by a
narrow channel of the M-th (third) level (branch
11). Correspondingly, there are three groups of
15   VBVCF channel sequences 165, 166, and 167
characterized by six bit words respectively
beginning with digit pairs 00, 01 or 11. Moving
further to the right along the branches of the
trellis diagram, nodes 162, 163 and 164 are met. At
20   these points choices are to be made as to which
elementary channels must be included in the desired
VBVCF channel sequence. Each trellis path crosses
the channelization frequency plan from the left to
the right, and is characterized by a six-bit word.
25   Each word also represents the VBVCF channel sequence
associated with a particular trellis path. For
example, channel sequence 70 of Fig. 5(b) is
characterized by the word 174="011110" relative to
the trellis path represented by a bolder dashed line
30   in Fig. 5(a).
          Fig. 5(c) shows how such a word is used to
control the SPmT switch array in a switching network
of the type shown in Fig. 3. Signals from the
first, second and third channelization levels 180,

182 and 184 are applied to the SPmT switch array 80
via an interconnect network 186. The SPmt switch
array includes four switches 188, 190, 192 and 194
corresponding to trellis nodes 161, 162, 163 and
164. SP3T switches correspond to three option nodes
and SP2T switches correspond to two option nodes in
the trellis diagram. A configuration of the SPmT
switch array is determined by a six-bit control
signal (CB 1,2,3,4,5,6) equal to the six-bit word
previously generated. The states of the switches
188, 190, 192 and 194 are defined by the first two
bits, the third bit, the forth and fifth bits, and
by the sixth bit, respectively. Controller 140
provides the control signals. The settings of the
switches of Fig. 5(c) are identified by black dots
at the two ends of the switch rotating arm, and are
made according to the word "011110". The four
outputs of the switch array provide the four
channels of sequence 70 indicated by the symbols ▲
□ ● △, The other channels in the sequence 70, all
belonging to the third channelization level are
directly coupled to the crossbar switch matrix.
These channels are indicated by a letter D in Fig.
5(a) (channels with crossed bars in Fig. 4).

      Once the designed VBVCF sequence of
elementary channels is obtained, different block
channels must be routed to different downlink beams.
For example, in Fig. 5(b), it is assumed that at a
certain instant of time, the channel sequence 70 is
split into three blocks 71, 72, and 73 destined to
downlink beams 1,2 and 3. The task of connecting
simultaneously non-overlapping frequency-multiplexed
channels to one output port is carried out by the
coupler crossbar matrix 90 of Fig. 5(c). The switch

points are of the type shown if Fig. 3. Encircled
black dots indicated closed switch points and
provide the correct connections to meet the routing
requirements 71, 72 and 73 of Fig. 5(b). The switch
controls for the switch matrix 90 are of
conventional type, consisting of five-bit words
applied to the matrix rows. There are four bits for
the addresses of sixteen switch points and a one-bit
state bit. In Fig. 5(c), the three words are
provided by control unit 140 and are indicated as
[CB 7,8,9,10,11]; [CB 12,13,14,15,16]; and [CB
17,18,19,20,21]. Note that in the example
described, a time plan has not been specified for
the switch controls, neither SSTDMA nor SSFDMA. For
the most general case, the preferred embodiment
utilizes a control unit 140 implemented by three
separate controllers -- an SSTDMA controller, a
SSFDMA controller and a SPmT switch array
controller.

Fig. 6 is a detailed block diagram of a
preferred on-board router according to an aspect of
the invention. Input beams from 1 to N_x < N support
VBVCF traffic. In describing transponder traffic
relative to a single beam, e.g. Beam No. 1, incoming
traffic occupies a bandwidth B_T centered at f_{TC} as
shown in Fig. 2. When switch 116 (which also may be
externally controlled like other switches in the CB
network) couples the input to the downconverter 111,
traffic signals are frequency translated by
downconverter 111 by means of local oscillator
frequencies f_{LO} + B'_x, previously described,
generated in the synthesized sources 114. A bypass
switch 115 connects the synthesized source to the
downconverter 111, or alternatively, allows

operation with B_x = 0. The bypass switch 116 allows the incoming traffic to bypass router processing and apply the incoming traffic directly to the CB connectivity network 12 (Fig. 1A).

Output signals from downconverter 111 are applied to a paralleling circuit 112, previously described in connection with paralleling circuit 46 of Fig. 2, via a connection transmission line 118. Paralleling circuit 112 splits traffic into two streams 121 and 122 which are forwarded to a bandpass filter 113 and to a channelizer 123, previously described in connection with channelizer 55 (Fig. 2) connected to a switching network 125, also previously described in connection with switch matrices of Fig. 3(a). The unit 120 contains the channelizer (CHAN), the paralleling circuit (PAR), the bandpass filter (BPF) and the switching network (SN).

The switching network 125 contains two major units: a Single Pole Multi Throw (SPMT) array 126 performing the "Variable Bandwidth" function, and a Cross Bar Switch Matrix (CBSM) 127 performing the "Variable Center Frequency" and routing of traffic to the downlink beams. The N_x outputs 128 from each of the units 120 are multiplexed back into N_x traffic channels in the output multiplexer 130. Traffic channels at the multiplexer's outputs 134, 135 and 136 are upconverted in the upconverters 141 before being sent to the router's output ports 142. Other units 120 and components thereof operate similarly.

While we have shown and described specific embodiments of this invention, further modifications and improvements will occur to those skilled in the

art. For example, bandwidths and frequency specifications illustrated were chosen for purposes of illustrations, and not as a limitation. The bandwidths and operating frequencies may take on a variety of forms and specifications without departing from teachings herein. Alternative frequency plans may be implemented, not just the one shown and described. Control of all switches may be accomplished by a variety of means, including a processor, relay, or by condition responsive means. Filtering may also be accomplished by a variety of means other than filter banks. For example, digital filtering may alternatively be employed with a concomitant substitution of appropriate components to match the technology of such digital filters in accordance with the teachings herein. Upconverting and downconverting may also be accomplished by various means other than by the use of frequency mixing with a synthesized source. Accordingly, the invention encompasses those modifications and alterations as may come to those skilled in the art based upon the teaching set forth herein and is not limited to the particular embodiments shown and/or described herein.

CLAIMS

1.   A variable bandwidth variable center-frequency
     multi-beam communications system for use in a satellite,
     which includes multiple transponder channels
     for interconnecting plural incoming and
     outgoing communications paths, said system
     comprising:

     A.   receiving means for receiving at least one
          incoming transponder channel of constant
          bandwidth,

     B.   band-splitting means connected with said
          receiving means for dividing the bandwidth
          of said at least one transponder channel
          into a first portion and a second portion,

     C.   multistage channelizing means connected
          with said band-splitting means for
          receiving said second portion of said at
          least one transponder channel, said
          channelizing means being operative for
          further dividing said second channel into
          multiple levels of subchannels of variable
          bandwidth, and

     D.   switching means for connecting one-out-of-
          many input signals with overlapping bands
          to one output port of said transponder at
          successive time intervals, and for
          simultaneously connecting plural input
          signals with non-overlapping band to one
          output port of said transponder.

2. A variable bandwidth variable center-frequency
    satellite communications system as recited in
    claim 1 further comprising means for varying
    the relative bandwidths of said first and
    second portions.

3. A variable bandwidth variable center-frequency
    satellite communications system as recited in
    claim 2 wherein said band-splitting means
    comprises manifolding means for distributing
    the signal between said first and second
    portion with minimal power loss, bandpass
    filter means for passing the first portion and
    power dividing means for dividing the signal
    power of said second portion.

4. A variable bandwidth variable center-frequency
    satellite communications system as recited in
    claim 3 wherein said manifolding means include
    amplifier means for amplifying the power of the
    signal of said first and second portions.

5. A variable bandwidth variable center-frequency
    satellite communications system as recited in
    claim 2 wherein said channelizing means
    comprises a plurality of selectable filter
    banks having high skirt selectivity.

6. A variable bandwidth variable center-frequency
    satellite communications system as recited in
    claim 5 wherein said filter banks comprises a
    plurality of groups of constant bandwidth
    filters to establish multilevel channelization
    in a parallel configuration thereby reducing

additive losses and distortion of a serial
configuration.

7.   A variable bandwidth variable center-frequency
      satellite communications system as recited in
      claim 6 wherein the filter banks of adjacent
      subchannels have asymmetric transmission
      amplitude characteristics at the edges thereof.

8.   A variable bandwidth variable center-frequency
      satellite communications systems as recited in
      claim 1 wherein said receiving means includes
      frequency translating means for translating the
      frequency of said at least one transponder
      channel.

9.   A variable bandwidth variable center-frequency
      satellite communications system as recited in
      claim 8 wherein the center-frequency of said
      translating means matches the center-frequency
      of said at least one transponder channel.

10.   A variable bandwidth variable center-frequency
      satellite communications system as recited in
      claim 9 wherein said frequency translating
      means comprises a local oscillator which
      includes means for generating a plurality of
      frequencies to effect center-frequency
      alignment of a plurality of said at least one
      transponder channel.

11. A variable bandwidth variable center-frequency
satellite communications system as recited in
claim 1 further comprising:

    E.   SSTDMA control means connected to said
switching means for effecting time-
division multiplexing of information
carried by said first portion and said
second portion of variable bandwidth.

12. A variable bandwidth variable center-frequency
satellite communications system as recited in
claim 1 further comprising:

    E.   SSFDMA control means connected to said
switching means for effecting frequency-
division multiple access of information
carrier by said first and second portions
of said at least one transponder channel.

13. A variable bandwidth variable center-frequency
satellite communications system as recited in
claim 1 further comprising:

    E.   SSTDMA control means connected to said
switching means for effecting time-
division multiplexing of information
carried by said first portion of constant
bandwidth and said second portion of
variable bandwidth, and

    F.   SSFDMA control means connected to said
switching means for effecting frequency-
division multiple access of information

carried by said first and second portions
of said at least one transponder channel.

14. A method for providing variable bandwidth
variable center-frequency multi-beam communi-
cation in a system for use in a satellite, which
includes multiple transponder channels for
interconnecting plural incoming and outgoing
communications paths, said method comprising
the steps of:

dividing the bandwidth of at least one of
said transponder channels into a first
portion at a first center frequency and a
second portion having a second center
frequency,

channelizing said second portion of the
transponder channels into a plurality of
groups of subchannels of successive levels
of selectable bandwidth, and

connecting, in accordance with traffic
demands, one-out-of-many input paths with
overlapping bands to one output port of
said transponder at successive time
intervals, and simultaneously connecting
plural input paths with non-overlapping
bands to one output port of said
transponder.

15. A method as recited in claim 14 further
comprising the step of:

controlling said connecting step by
effecting frequency-division multiple·
access of said respective input and output
paths of said at least one transponder
channel.

16. A method as recited in claim 14 further
comprising the step of:
controlling said connecting step by
effecting time-division multiple access of
said respective input and output paths of
said at least one transponder channel.

17. A method as recited in claim 14 further
comprising the step of:
controlling said connecting step by
effecting frequency-division or time-
division multiple access of said
respective input and output paths of said
at least one transponder channel in
accordance with traffic demands.

18. A method as recited in claim 14 wherein said
controlling step further includes the step of
effecting both time-division and frequency-
division multiple access among respective input
and output paths.

19. A method as recited in claim 14 wherein said
dividing step includes the step of frequency-
translating said at least one transponder
bandwidth to first and second bands of
frequencies to define said first and second
portions.

20. A method as recited in claim 15 wherein said dividing step includes the step of frequency-translating said at least one transponder bandwidth to first and second bands of frequencies to define said first and second portions.

21. A method as recited in claim 14 wherein said channelizing step includes the step of power dividing said second portion into M stages each having n equal narrowband levels, where M and n are integers.

22. Communications systems for satellites, substantially as hereinbefore described with reference to any one or more of the accompanying drawings.

23. A satellite provided with a communications system as claimed in any of claims 1 to 13 or 22.

24. A multi-beam communications system including a satellite as claimed in claim 23.

25. The methods of providing variable bandwith variable centre-frequency multi-beam communication for use in satellites, substantially as hereinbefore described.

26. A multi-beam communications system operable in accordance with the method claimed in any of claims 14 to 21 or 25.

Amendments to the claims have been filed as follows

41

CLAIMS

1. A variable bandwidth variable center-frequency
    multi-beam communications system for use in a satellite,
    which includes multiple transponder channels
    for interconnecting plural incoming and
    outgoing communications paths, said system
    comprising:

    A. receiving means for receiving at least one
        incoming transponder channel of constant
        bandwidth,

    B. band-splitting means connected with said
        receiving means for dividing the bandwidth
        of said at least one transponder channel
        into a first portion and a second portion,

    C. multistage channelizing means connected
        with said band-splitting means for
        receiving said second portion of said at
        least one transponder channel, said
        channelizing means being operative for
        further dividing said second portion into
        multiple levels of subchannels of variable
        bandwidth, and

    D. switching means for connecting one-out-of-
        many input signals with overlapping bands
        to one output port of said transponder at
        successive time intervals, and for
        simultaneously connecting plural input
        signals with non-overlapping band to one
        output port of said transponder.